Original Article

Ann Rehabil Med 2026;50(1):62-70
eISSN: 2234-0653
https://doi.org/10.5535/arm.250061

Annals of Rehabilitation Medicine

# Effectiveness of the National Health Screening Program for Infants and Children in Detecting Neurodevelopmental Disorders: A Nationwide Population-Based Analysis

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**Objective:** To evaluate the effectiveness of the National Health Screening Program for Infants and Children (NHSPIC) in the early diagnosis of neurodevelopmental disorders (NDDs) utilizing data from the National Health Insurance Database of South Korea.

**Methods:** We enrolled children born between 2011 and 2018 who completed the first to fourth stages of the NHSPIC. A positive finding was defined as a recommendation for further evaluation during one or more stages. Participants were categorized into the positive and negative finding groups. Following 1:1 propensity score matching, 82,138 participants were assigned to each group.

**Results:** Comparative analysis revealed that participants with positive findings exhibited a higher risk of developing all seven NDDs, particularly for autism spectrum disorder (hazard ratio [HR], 19.70; 95% confidence interval [CI], 17.48–22.20), intellectual disability (HR, 17.11; 95% CI, 14.69–19.93), developmental language disorder (HR, 11.74; 95% CI, 10.73–12.84), and cerebral palsy (HR, 11.34; 95% CI, 8.67–14.84). The HR for learning disability was 4.31 (95% CI, 2.94–6.34), whereas attention-deficit hyperactivity disorder had an HR of 3.57 (95% CI, 3.37–3.78). Tic disorder had the lowest HR (HR, 1.64; 95% CI, 1.48–1.82). Additionally, HRs were calculated for each NHSPIC stage, demonstrating the utility of specific stages in the early detection of each NDD.

**Conclusion:** Developmental screening tests in the NHSPIC contributed to the early diagnosis of NDDs. This study underscores the significance of the NHSPIC and provides foundational evidence to inform and enhance policies related to child health screenings.

**Keywords:** Child, Mass screening, National health programs, Neurodevelopmental disorders, Propensity score

**Received:** May 8, 2025
**Revised:** November 6, 2025
**Accepted:** February 2, 2026

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## INTRODUCTION

Neurodevelopmental disorders (NDDs) encompass a broad spectrum of conditions that affect various developmental domains, including gross and fine motor skills, speech and language, cognition, social functioning, and activities of daily living [1]. Early assessment and intervention are pivotal in optimizing outcomes in children with NDDs, with the critical window of

opportunity occurring during the early stages of brain development [2]. Early detection is essential for timely intervention, prompting the implementation of various developmental screening programs worldwide.

Since the early 2000s, South Korea's declining birth rate and aging population have underscored the need to strengthen social support systems for childbirth and child-rearing. However, until the early 2000s, national screening programs had not been implemented. In contrast, countries such as Japan, Germany, and the United States had already established developmental screening programs with age-specific, professional assessments [3-5]. Based on the precedents, the National Health Screening Program for Infants and Children (NHSPIC) was launched in November 2007, incorporating examiner-led assessments alongside caregiver questionnaires.

The NHSPIC consists of seven screening stages conducted from 4 to 71 months of age, with an additional newborn stage introduced in 2021. The first stage included a medical history, physical examination, and measurements, whereas developmental screening tests were added from the second stage. Supplementary Table S1 presents the schedule and detailed developmental domains of each stage, based on developmental screening with the Korean version of the Ages and Stages Questionnaire and the Korean Developmental Screening Test (K-DST). During the screening process, the examiner evaluates whether the caregiver has overestimated the child's developmental progress or provided inconsistent responses. If necessary, the child may be required to perform the assessment items directly as part of the screening. Furthermore, if a definitive concern, such as developmental delay, is identified through history taking and evaluations, further evaluation may be recommended, even in cases where a "need for follow-up" is indicated by the surveillance tool.

Previous studies have examined the effectiveness of developmental screening tests in diagnosing NDDs. One study confirmed the reliability and validity of the K-DST within the NHSPIC but did not establish its clinical effectiveness [6]. Another study examined the rate of developmental disorder diagnoses after positive NHSPIC results, yet it did not directly assess the program's impact on NDD diagnosis [7]. Accordingly, further research is needed to evaluate the effectiveness of the NHSPIC. To date, no research has quantitatively compared NDD incidence between children with and without positive NHSPIC findings. Therefore, this study aims to evaluate the strength of the association between NHSPIC results and early detection of NDDs, thereby clarifying the program's clinical significance.

## METHODS

### Data collection

We conducted a nationwide, population-based analysis using data from the National Health Information Database (NHID). The NHID is provided by the National Health Insurance Service, the sole public medical insurance provider in South Korea, covering over 99% of the Korean population. The NHID includes comprehensive records of sociodemographic variables, healthcare utilization, and clinical diagnoses.

### NDDs included in this study

The NDDs included in the analysis were cerebral palsy (CP), developmental language disorder (DLD), intellectual disability (ID), learning disability (LD), autism spectrum disorder (ASD), attention-deficit hyperactivity disorder (ADHD), and tic disorder. These conditions were identified using corresponding diagnostic codes of the International Classification of Diseases, Tenth Revision (Supplementary Table S2). The occurrence of an NDD was defined as either two outpatient visits or one hospitalization, in which the relevant diagnostic code was listed as the primary or first secondary diagnosis.

### Participants

We included all children born between 2011 and 2018 and followed them up until 2022 using data from the NHID. We included children who completed all screening stages from the first to the fourth, up to 36 months of age, to assess the effectiveness of early diagnosis of NDDs through the NHSPIC. A positive finding was defined as receiving a recommendation for further evaluation in one or more of the second to fourth stages, which was based on scoring below -2 standard deviations. Children who did not receive further evaluation recommendations in any of these stages were classified as having a negative finding. A 1:1 propensity score matching was performed between the two groups to control for potential confounding variables that could influence the occurrence of NDDs. The variables included in the matching process were birth year, sex, birth weight, prematurity, residential area, and income group (based on insurance premium percentiles).

We included only cases where an NDD was diagnosed after the screening in our analysis to focus on the ability of NHSPIC

to detect NDDs. Participants in the positive finding group who had been diagnosed with an NDD before receiving a positive finding were excluded (Fig. 1). Participants from the negative finding group who were matched with these excluded individuals were omitted from the analysis. Furthermore, any deceased participants, along with their matched counterparts, were excluded to ensure accurate comparisons. Given the differing observation periods for each participant, the analysis specifically accounted for the time from the index date to the NDD diagnosis for each individual. For the positive finding group, the index date was defined as the date when the positive finding was first identified in the developmental screening test. For the negative finding group, the index date was defined as the date corresponding to when their matched counterpart in the positive finding group first exhibited a positive finding.

### Statistical analysis

Demographics before and after propensity score matching were compared between the positive and negative finding groups. Categorical variables are presented as numbers and percentages. There were no continuous demographic variables. We used the chi-square test to compare categorical variables. Propensity scores were calculated using a multivariable logistic regression model. We performed 1:1 nearest neighbor matching with a caliper width of 20% of the estimated propensity scores. We used Cox proportional hazards models to estimate hazard ratios (HRs) with corresponding 95% confidence intervals (CIs). A two-sided p-value<0.05 was considered statistically significant. All statistical analyses were performed using SPSS Statistics version 26 (IBM Corp.).

The Institutional Review Board of National Health Insurance Service Ilsan Hospital reviewed and approved this study (NHIMC 2023-03-029). The ethics committee waived the need for written consent.

## RESULTS

Among the 3,181,991 children born between 2011 and 2018, 1,623,927 who completed all NHSPIC screenings up to 36 months were included. Of these, 1,541,789 were classified as the negative finding group, whereas 82,138 were classified as the positive finding group. Following 1:1 propensity score matching, 82,138 participants were retained in each group (Fig. 2).

Table 1 presents the demographic factors of the two groups before and after propensity score matching. Significant differences were observed between the two groups in the crude analysis prior to matching. Both groups had a higher proportion of males than females, with the positive finding group showing a significantly higher proportion of males than the negative finding group. In terms of birth weight, the majority of participants in both groups weighed between 2.5 and 3.5 kg, followed by those weighing >3.5 kg, with the smallest proportions in the 1.5–2.5 kg and <1.5 kg categories. Prematurity rates were significantly higher in the positive finding group (7.28%) than in the negative finding group (3.82%). However, after propensity score matching, no statistically significant differences were observed between the two groups.

The incidence rates of each NDD among the remaining participants were compared between the two groups, revealing significant differences across all NDDs (Table 2). The comparative analysis, conducted through Cox proportional hazards model, revealed high HRs for diagnoses of several NDDs, particularly

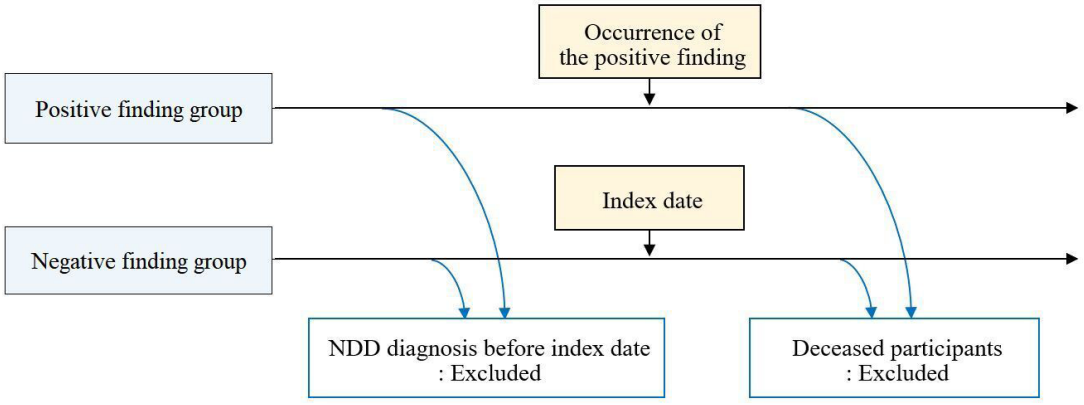


**Fig. 1.** Schematic timeline of the study process. NDD, neurodevelopmental disorder.

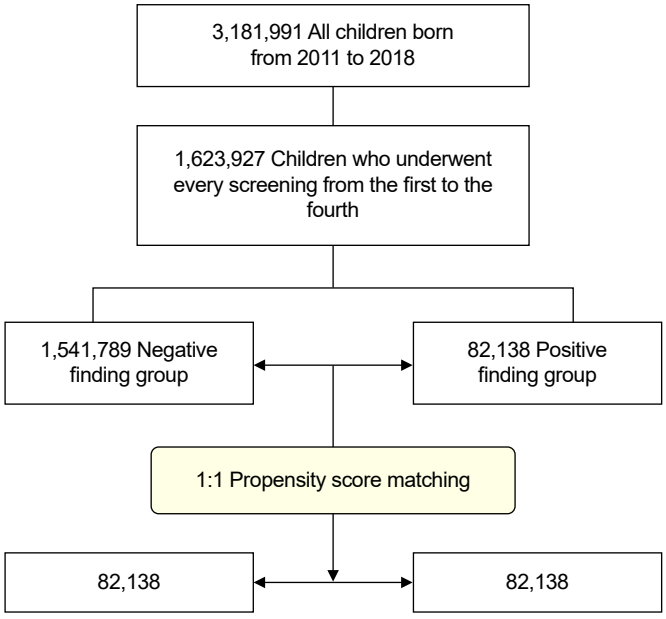


**Fig. 2.** Flow chart of the study population selection.

for ASD (HR, 19.70; 95% CI, 17.48–22.20), ID (HR, 17.11; 95% CI, 14.69–19.93), DLD (HR, 11.74; 95% CI, 10.73–12.84), and CP (HR, 11.34; 95% CI, 8.67–14.84). LD had an HR of 4.31 (95% CI, 2.94–6.34), whereas ADHD had an HR of 3.57 (95% CI, 3.37–3.78). Tic disorder showed the lowest HR among the NDDs (HR, 1.64; 95% CI, 1.48–1.82) (Table 2, Fig. 3).

To further analyze which stages of the NHSPIC indicate a higher risk for each NDD, HRs were calculated for each screening stage (Table 3, Fig. 4). For CP, the HR progressively decreased from the second to the fourth screening stage. In contrast, HRs for ID, DLD, and ASD increased from the second to the fourth stage. ADHD showed no substantial difference in HR across the stages, although a slightly increasing trend was observed. The HRs for LD and tic disorder remained consistent across the second to fourth screening stages.

## DISCUSSION

In this study, stratification was performed based on demographic characteristics, including birth year, sex, birth weight,

**Table 1.** Demographic factors before and after propensity score matching

| Demographic factor | | Crude analysis | | p-value | Post-propensity score matching | | p-value |
|---|---|---|---|---|---|---|---|
| | | Negative finding (N=1,541,789) | Positive finding (N=82,138) | | Negative finding (N=82,138) | Positive finding (N=82,138) | |
| Birth year | 2011 | 146,119 (9.48) | 3,976 (4.84) | <0.001 | 3,973 (4.84) | 3,976 (4.84) | >0.99 |
| | 2012 | 182,598 (11.84) | 6,664 (8.11) | | 6,661 (8.11) | 6,664 (8.11) | |
| | 2013 | 183,106 (11.88) | 7,699 (9.37) | | 7,698 (9.37) | 7,699 (9.37) | |
| | 2014 | 194,625 (12.62) | 10,951 (13.33) | | 10,959 (13.34) | 10,951 (13.33) | |
| | 2015 | 220,277 (14.29) | 12,719 (15.48) | | 12,717 (15.48) | 12,719 (15.48) | |
| | 2016 | 214,788 (13.93) | 13,465 (16.39) | | 13,466 (16.39) | 13,465 (16.39) | |
| | 2017 | 207,008 (13.43) | 13,354 (16.26) | | 13,354 (16.26) | 13,354 (16.26) | |
| | 2018 | 193,268 (12.54) | 13,310 (16.20) | | 13,310 (16.20) | 13,310 (16.20) | |
| Sex | Male | 780,062 (50.59) | 56,360 (68.62) | <0.001 | 56,374 (68.63) | 56,360 (68.62) | 0.94 |
| | Female | 761,727 (49.41) | 25,778 (31.38) | | 25,764 (31.37) | 25,778 (31.38) | |
| Birth weight (kg) | <1.5 | 3,225 (0.21) | 669 (0.81) | <0.001 | 671 (0.82) | 669 (0.81) | >0.99 |
| | 1.5–2.5 | 68,735 (4.46) | 6,139 (7.47) | | 6,137 (7.47) | 6,139 (7.47) | |
| | 2.5–3.5 | 1,067,130 (69.21) | 55,046 (67.02) | | 55,048 (67.02) | 55,046 (67.02) | |
| | ≥3.5 | 402,699 (26.12) | 20,284 (24.70) | | 20,282 (24.69) | 20,284 (24.70) | |
| Prematurity | Yes | 58,958 (3.82) | 5,978 (7.28) | <0.001 | 5,971 (7.27) | 5,978 (7.28) | 0.95 |
| | No | 1,482,831 (96.18) | 76,160 (92.72) | | 76,167 (92.73) | 76,160 (92.72) | |
| Residential area | Seoul | 296,065 (19.20) | 15,384 (18.73) | <0.001 | 15,377 (18.72) | 15,384 (18.73) | >0.99 |
| | Metropolitan cities | 395,232 (25.63) | 22,311 (27.16) | | 22,309 (27.16) | 22,311 (27.16) | |
| | Others | 850,492 (55.16) | 44,443 (54.11) | | 44,452 (54.12) | 44,443 (54.11) | |
| Income group | First (lowest) | 2,633 (0.17) | 364 (0.44) | <0.001 | 347 (0.42) | 364 (0.44) | 0.98 |
| | Second | 141,755 (9.19) | 8,388 (10.21) | | 8,381 (10.20) | 8,388 (10.21) | |
| | Third (middle) | 294,818 (19.12) | 17,168 (20.90) | | 17,184 (20.92) | 17,168 (20.90) | |
| | Fourth | 648,822 (42.08) | 34,324 (41.79) | | 34,332 (41.80) | 34,324 (41.79) | |
| | Fifth (highest) | 453,761 (29.43) | 21,894 (26.66) | | 21,894 (26.66) | 21,894 (26.66) | |

Values are presented as number (%).

**Table 2.** Comparison of diagnosis for NDDs between the negative and positive finding groups

| Clinical diagnosis | Total number after exclusion | Negative finding | Positive finding | p-value | HR (95% CI) |
|---|---|---|---|---|---|
| CP | 81,544 | 58 (0.07) | 658 (0.81) | <0.001 | 11.34 (8.67–14.84) |
| ID | 82,025 | 184 (0.22) | 2,999 (3.66) | <0.001 | 17.11 (14.69–19.93) |
| DLD | 80,814 | 542 (0.67) | 6,098 (7.55) | <0.001 | 11.74 (10.73–12.84) |
| LD | 82,136 | 32 (0.04) | 138 (0.17) | <0.001 | 4.31 (2.94–6.34) |
| ASD | 81,343 | 299 (0.37) | 5,586 (6.87) | <0.001 | 19.70 (17.48–22.20) |
| ADHD | 82,097 | 1,583 (1.93) | 5,396 (6.57) | <0.001 | 3.57 (3.37–3.78) |
| Tic disorder | 82,123 | 588 (0.72) | 958 (1.17) | <0.001 | 1.64 (1.48–1.82) |

Values are presented as number (%).
NDDs, neurodevelopmental disorders; CP, cerebral palsy; ID, intellectual disability; DLD, developmental language disorder; LD, learning disability; ASD, autism spectrum disorder; ADHD, attention-deficit hyperactivity disorder; HR, hazard ratio; CI, confidence interval.

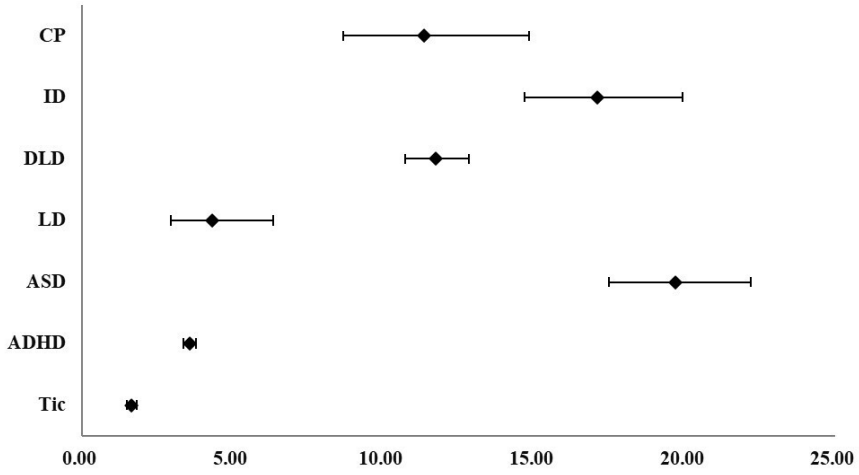


**Fig. 3.** Forest plot of hazard ratios and confidence intervals for NDDs. NDDs, neurodevelopmental disorders; CP, cerebral palsy; ID, intellectual disability; DLD, developmental language disorder; LD, learning disability; ASD, autism spectrum disorder; ADHD, attention-deficit hyperactivity disorder; Tic, tic disorder.

prematurity, residential area, and income group, which could be associated with the occurrence of NDDs. The crude analysis revealed that the positive finding group had a significantly higher proportion of male individuals than the negative finding group. This result aligns with previous findings that male sex is a risk factor for NDDs, such as DLD, ASD, and ADHD, which have a higher prevalence in male individuals [8-10]. Preterm birth can affect all aspects of neurological development. Therefore, prematurity and birth weight, as factors related to preterm delivery, were selected as demographic factors [11]. Compared with the negative finding group, the positive finding group showed a significantly higher proportion of prematurity and low birth weight. Low socioeconomic status has been significantly associated with the occurrence of NDDs, such as CP, DLD, and ID. In this study, the positive finding group had a significantly higher proportion of individuals in the low-income group than the negative finding group [12-14].

CP, ID, DLD, and ASD showed high HRs in the comparative analysis, suggesting that the developmental screening items in the NHSPIC are closely associated with the clinical manifestations of these conditions. A previous cross-tabulation analysis comparing existing tools for assessing language development and autism with the K-DST confirmed a correlation between the K-DST results and the severity of autism and language delays, as measured by the existing tools [15]. The result is consistent with our findings, showing that the diagnostic rates of DLD and ASD were highly correlated with positive findings in the developmental screening tests. In contrast, another study discovered that the screening effectiveness of the NHSPIC was lower for CP, ID, and ASD compared with other NDDs, potentially owing to the higher proportion of children who either did not undergo screening or were already diagnosed for these con-

**Table 3.** HRs and CIs of NDDs for each stage

| Clinical diagnosis | 2nd (9–12 mo) | 3rd (18–24 mo) | 4th (30–36 mo) |
|---|---|---|---|
| | | HR (95% CI) | |
| CP | 16.84 (11.25–25.21) | 9.60 (5.64–16.34) | 5.17 (3.12–8.56) |
| ID | 11.94 (8.97–15.89) | 17.79 (13.49–23.46) | 20.31 (16.00–25.77) |
| DLD | 5.52 (4.72–6.46) | 13.04 (11.20–15.17) | 17.80 (15.12–20.96) |
| LD | 4.50 (1.86–10.90) | 3.80 (1.89–7.63) | 4.56 (2.66–7.84) |
| ASD | 9.26 (7.45–11.50) | 23.27 (18.89–28.67) | 25.75 (21.11–31.42) |
| ADHD | 2.27 (2.03–2.53) | 3.79 (3.39–4.22) | 4.36 (4.00–4.75) |
| Tic disorder | 1.41 (1.16–1.73) | 1.81 (1.50–2.18) | 1.68 (1.44–1.96) |

HRs, hazard ratios; CIs, confidence intervals; NDDs, neurodevelopmental disorders; CP, cerebral palsy; ID, intellectual disability; DLD, developmental language disorder; LD, learning disability; ASD, autism spectrum disorder; ADHD, attention-deficit hyperactivity disorder.

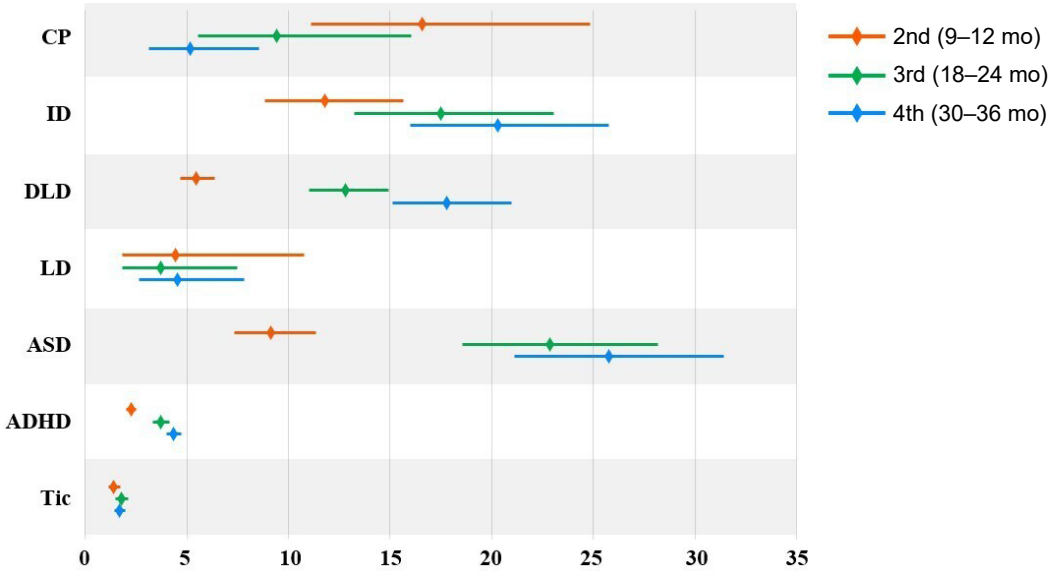


**Fig. 4.** Forest plot of hazard ratios and confidence intervals of NDDs for each stage. NDDs, neurodevelopmental disorders; CP, cerebral palsy; ID, intellectual disability; DLD, developmental language disorder; LD, learning disability; ASD, autism spectrum disorder; ADHD, attention-deficit hyperactivity disorder; Tic, tic disorder.

ditions before obtaining positive findings during the screening [7]. In our study, we only included participants who received a diagnosis after NHSPIC screening to focus on the screening effectiveness. This approach may explain the differences between our findings and those of previous studies.

The HRs for LD and ADHD were 4.31 and 3.57, respectively, showing significantly higher diagnostic rates in the positive finding group compared with the negative finding group. However, these HRs were lower than those for other diseases. As LD is diagnosed when impairments are observed in specific academic domains such as reading, written expression, or mathematics, the clinical manifestations suggesting LD are challenging to detect before school age [16]. According to a previous systematic review, the reported age of onset for ADHD ranges from 2.25 to 7.5 years, whereas the age of diagnosis ranges from 6.2 to 18.1 years. Even when symptoms are suspected, a minimum observation period of 6 months is typically required, leading to a relatively late diagnosis [17]. Therefore, evaluations conducted after 36 months of age may be more meaningful for screening LD and ADHD. Further examination is needed to analyze whether the developmental screening tests in the sixth to eighth stages of the NHSPIC (up to 71 months) can diagnose LD and ADHD.

The HR for tic disorder was 1.64, which is relatively close to 1. Tic disorder is characterized by sudden, rapid, recurrent, non-rhythmic, and stereotyped motor movements or vocalizations [18,19]. The gross motor, fine motor, and language domains are used to evaluate a child's ability to perform devel-

opmentally appropriate tasks for their age. Thus, the characteristics required for diagnosing tic disorder are difficult to detect through developmental screening tests, potentially explaining the relatively low HR observed.

Previous studies have demonstrated that early diagnosis and intervention in NDDs can substantially influence clinical outcomes. Early and diagnostic-specific interventions in children with CP are essential to optimize neuroplasticity, improve functional abilities, and prevent secondary complications [20]. In children with ASD, early intervention can reduce developmental and behavioral barriers to participation in educational contexts [21]. A study by Carter et al. [22] emphasized the importance of early diagnosis and intervention for NDDs, particularly global developmental delay, ID, and ASD, through the differentiation of genetic and metabolic diseases. The efficacy of evaluation tools for diagnosing NDDs has been investigated. One study using receiver operating characteristic curve analysis demonstrated a high accuracy of the K-DST in screening for CP, DLD, ASD, and ID [6]. Another study on the screening effectiveness of the developmental screening tests in the NHSPIC divided participants into groups based on the presence of positive findings and whether NDD was diagnosed, and then calculated diagnosis rates to analyze the effect [7]. However, to our knowledge, no previous studies have quantitatively assessed the correlation between NHSPIC results and the early diagnosis of NDDs using HRs. In this study, we examined the strength of the association between the developmental screening tests of the NHSPIC and NDD diagnosis in children aged <36 months, thereby confirming that the NHSPIC contributes to the early diagnosis of NDDs.

Further, we aimed to determine the NHSPIC stage that is most strongly associated with the diagnosis of each NDD. Previous research has not analyzed the relationship between specific stages of the NHSPIC and NDD diagnosis. The HR for CP was highest in the second stage of the NHSPIC, possibly because of the relatively younger age at which CP is diagnosed. A study on referral age for CP diagnosis reported an average referral age of 16.6 months, with 57% of children referred before 12 months [23]. In contrast, the HR for ID, DLD, ASD, and ADHD increased as the children aged. These conditions are diagnosed based on assessments of language, cognitive function, and social behavior. The domains related to language, cognitive function, and social behavior in developmental screening tests become progressively more complex and challenging as a child's age increases, facilitating the identification of children with these conditions. Therefore, as the stages of the NHSPIC progress, the association with the occurrence of diagnoses may become stronger.

The checkup rate for NHSPIC is 80.7%, the highest among health screening programs conducted in South Korea [24]. However, no policies or institutional systems can directly link in-depth medical consultations following the screening. Additionally, the actual rate of hospital visits after receiving abnormal findings from the screening remains unknown. Our findings provide foundational data for strengthening institutional support and policies related to health screenings and in-depth medical evaluations for children.

## Limitations

This study has several limitations. First, the observation periods for participants varied. To address this, we used HRs for analysis and performed 1:1 propensity score matching for birth year and screening period. Second, we did not consider the specific domain of the developmental screening test that resulted in a positive finding. Another limitation arises from the structure of the NHSPIC: children who receive a positive finding but do not undergo further evaluation cannot subsequently be diagnosed with an NDD. Consequently, even if they are likely to have an NDD, they are not classified as such in diagnostic codes, resulting in potential false positives attributable to program design. Finally, this study focused on early diagnosis of NDDs by analyzing the NHSPIC stages for children aged 4–36 months, although the NHSPIC extends to children aged up to 71 months. Therefore, future studies should include screenings after the fourth stage, particularly for detecting conditions, such as LD and ADHD, which are generally diagnosed at relatively older ages.

## Conclusions

We confirmed that the risk of being diagnosed with specific NDDs was significantly higher in the group that received a recommendation for further evaluation from the developmental screening tests of the NHSPIC compared with those who did not. Additionally, we analyzed the NHSPIC stages most strongly associated with each NDD diagnosis. Consequently, our findings confirm the substantial contribution of the developmental screening tests in the NHSPIC to the early diagnosis of NDDs. This study provides evidence of the importance of the NHSPIC and serves as foundational data for strengthening policies related to child health screenings and comprehensive medical evaluations.

## CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

## FUNDING INFORMATION

This study was supported by the 2023 National Health Insurance Service Ilsan Hospital grant (NHIMC-2023-CR-018).

## AUTHOR CONTRIBUTION

Conceptualization: Kim SW. Methodology: Hong S. Formal analysis: Youk T. Funding acquisition: Hong S. Project administration: Hong S. Visualization: Yoo NY. Writing – original draft: Kim SW, Kim Y. Writing – review and editing: Hong S, Yoo NY. Approval of final manuscript: all authors.

## ACKNOWLEDGMENTS

This study used the National Health Information Database (NHIS-2023-1-481), made by the National Health Insurance Service.

## SUPPLEMENTARY MATERIALS

Supplementary materials can be found via https://doi.org/10.5535/arm.250061.

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